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TRIGGERING FOR A HETERODYNE INTERFEROMETER

Background Information

The present invention relates to a method for triggering a heterodyne interferometer having two acousto-optical modulators situated in separate light paths, a receiver which generates an analog signal and a downstream A/D converter which converts the analog signal into a digital signal, the one acousto-optical modulator being triggered at a modulation frequency f_1 and the other acousto-optical modulator being triggered at another modulation frequency f_2, the difference between modulation frequencies f_1 and f_2 forming a heterodyne frequency f_{Het}, and the analog signal being converted to a digital signal in the A/D converter at sampling frequency f_a.

The present invention also relates to a device including a triggering unit and a heterodyne interferometer having two acousto-optical modulators situated in separate light paths, a receiver which supplies an analog signal and a downstream A/D converter for forming a digital signal from the analog signal, the one acousto-optical modulator being triggered at a modulation frequency f_1 and the other acousto-optical modulator being triggered at another modulation frequency f_2 and the difference between modulation frequencies f_1 and f_2 corresponding to a heterodyne frequency f_{Het} and a sampling frequency f_a being provided for conversion of the analog signal into the digital signal.

Heterodyne interferometers are used to measure the phase shift of a beam of light caused by an optical phase shifter. The

length of an optical bypass line whose length is to be measured may function as an optical phase shifter. Heterodyne interferometers are already sufficiently well known from the technical literature.

In a heterodyne interferometer, the beam of a light source, usually a laser, is passed through a beam splitter to two acousto-optical modulators. The two acousto-optical modulators are triggered by frequencies f_1 and f_2 which are typically in the MHz range. The beams of light at the output of the acousto-optical modulators are shifted here by a corresponding frequency with respect to the original light frequency.

The two frequency-shifted beams of light are then sent back to a beam splitter via mirrors and combined, one of the two beams being delayed via an optical phase shifter. This may be accomplished via materials which shift the phase of light or with which the speed of the light with respect to air is reduced. According to another embodiment, the light is deflected by additional mirrors and must therefore travel through an optical bypass. After the two beams of light have been combined again by the beam splitter, e.g., in the form of a semitransparent mirror, the light is sent to a receiver containing a photodetector and usually an amplifier.

The two beams of light cause interference and generate a beat frequency known as a heterodyne frequency f_{Het} in the receiver. This frequency is calculated as follows:

$$f_{Het} = |f_1 - f_2|.$$

The phase of this signal, based on the phase angle of an electric signal of frequency f_{Het} obtained by mixing f_1 with f_2, corresponds to the phase shift of the optical phase shifter that is to be measured.

The analog signal available at the output of the receiver is sent to a downstream A/D converter which generates a digital signal. The conversion is then performed at a sample rate of frequency f_a. The digital signal is then sent to an analyzer unit for further processing.

In the case of the heterodyne interferometers described above, generating frequencies f_1, f_2 and f_a during operation may result in great fluctuations in heterodyne frequency $f_{Het} = |f_1 - f_2|$ because the oscillators may have frequency drift with temperature and also with aging. Another disadvantage is that blanking frequency f_a does not form an integral ratio with heterodyne frequency f_{Het} and is not even constant.

The object of the present invention is to provide a method for triggering a heterodyne interferometer that will not have these disadvantages. Another object of the present invention is to provide a corresponding device including a triggering device of a heterodyne interferometer.

Advantages of the Invention

The object of the present invention relating to the method is achieved by forming at least two of the frequencies of modulation frequencies f_1, f_2 and sampling frequency f_a from a fundamental frequency f_{quartz} of a common oscillator. A fixed ratio of modulation frequencies may be achieved in this way and the modulation frequencies will not undergo shifts due to

aging and drift. In addition, sampling frequency f_a is then in a fixed phase ratio to the differential frequency of modulation frequencies f_1, f_2, i.e., heterodyne frequency f_{Het}. Measurement accuracy is increased because sampling is performed at a constant phase, independently of drift and aging.

If modulation frequencies f_1 and f_2 are generated from fundamental frequency f_{quartz} using the method of direct digital synthesis (DDS) by incrementing a digital accumulator of word width N by an integer Z for each clock pulse of the oscillator designed as a quartz oscillator having fundamental frequency f_{quartz}, the signals may be supplied inexpensively in a strictly digital manner. Furthermore, the modulation frequencies may be freely programmed with these signals.

If modulation frequencies f_1 and f_2 are generated separately from fundamental frequency f_{quartz} in separate DDS units, inexpensive commercially available integrated circuits may be used.

According to an embodiment having a linear phase course which is particularly easy to implement, a sawtooth-shaped value curve of the contents of the digital accumulator is obtained by incrementing the digital accumulator.

A particularly suitable strictly sinusoidal triggering for modulation of acousto-optical modulators is achieved by interpreting the value curve in the digital accumulator as a phase value of a cosine oscillation, determining a sample of a cosine oscillation using a table stored in a ROM and/or algorithmic methods from the phase value and smoothing them in an analog low-pass filter.

In a simplified circuit design, sampling frequency f_a for the A/D converter is formed by a divider unit from modulation frequency f_1 or sampling frequency f_a for the A/D converter is formed by a divider unit from modulation frequency f_2, thus making it possible to eliminate an additional oscillator.

Measurement accuracy is improved if sampling frequency f_a is an integral multiple of heterodyne frequency f_{Het}.

If the ratio between sampling frequency f_a and heterodyne frequency f_{Het} is a factor of at least 2, good measurement accuracy is achieved with minimal circuit complexity.

The object of the present invention relating to the device is achieved by the fact that the triggering device for generating at least two of the frequencies, i.e., from modulation frequencies f_1, f_2 and sampling frequency f_a, has a common oscillator having fundamental frequency f_{quartz}. This achieves a measurement accuracy which does not depend on drift or component aging and does so with minimal circuit complexity.

According to a preferred embodiment, a direct digital synthesizer (DDS) is provided for generating modulation frequencies f_1 and f_2 from fundamental frequency f_{quartz} and has a digital accumulator of word width N which is incrementable by an integer Z via an incrementation stage for each clock unit of oscillator 100 which has a clock frequency f_{quartz} and is designed as a quartz oscillator. As a result, signals are generated inexpensively in a digital manner and are programmed freely.

If separate DDS units are provided for generating modulation frequencies f_1 and f_2, inexpensive commercially available components may be used.

In a simplified circuit design, a divider unit is provided for generating sampling frequency f_a from modulation frequency f_1 or a divider unit is provided for generating sampling frequency f_a from modulation frequency f_2.

In a preferred embodiment, the division ratio of the divider unit is an integer. This yields a particularly good measurement accuracy.

In a simple embodiment having good measurement accuracy, the division ratio of the divider unit is at least 2.

Drawing

The present invention is explained in greater detail below on the basis of an exemplary embodiment as illustrated in the figures.

Figure 1 schematically shows a heterodyne interferometer according to the related art;

Figure 2 schematically shows an oscillator system for a heterodyne interferometer;

Figure 3 schematically shows another embodiment of an oscillator system.

Description of the Exemplary Embodiments

Figure 1 schematically shows a heterodyne interferometer 1 known from the related art.

The beam of a light source 10 is passed through a beam splitter 50 to two acousto-optical modulators 20, 30, labeled as AOM1 and AOM2 in the figure. Acousto-optical modulators 20, 30 are triggered at frequencies f_1 and f_2, typically in the MHz range. The beams of light at the output of acousto-optical modulators 20, 30 are shifted by the corresponding frequency with respect to the original light frequency. Light source 10 is preferably a laser having a long coherence length. The two frequency-shifted beams of light are then sent via mirrors 60 back to a beam splitter 50 and combined, one of the two beams being delayed by an optical phase shifter 40. This may be accomplished by using materials that shift the phase of light or in which the speed of the light is reduced with respect to air. According to another embodiment, light is deflected by additional mirrors and therefore must pass through an optical bypass. After the two beams of light have been combined again by beam splitter 50, e.g., in the form of a semitransparent mirror, the light is sent to a receiver 70. Receiver 70 is designed by a photodetector having a downstream amplifier that supplies an analog signal 71. The amplifier may be integrated into receiver 70.

Both beams of light produce interference and generate a beat frequency known as heterodyne frequency f_{Het}, in receiver 70. This frequency is calculated by the formula

$$f_{Het} = |f_1 - f_2|.$$

The phase of this signal based on the phase angle of an electric signal of frequency f_{Het} obtained by mixing f_1 with f_2

corresponds to the phase shift of optical phase shifter 40 that is to be measured.

Analog signal 71 which is available at the output of receiver 70 is sent to a downstream A/D converter 80 which generates a digital signal 81. The conversion takes place at a sampling rate of frequency f_a. Digital signal 81 is then sent to an analyzer unit 90 for further processing.

According to the related art, frequencies f_1, f_2 and f_a are obtained from separate quartz oscillators, which have the same disadvantages as those mentioned above with regard to the stability of the frequency ratio.

Figure 2 shows an oscillator system for a heterodyne interferometer according to the present invention.

To generate AOM frequencies f_1 and f_2, the DDS method, i.e., direct digital synthesis, is used. In this method a digital accumulator of word width N is incremented by an integer Z for each clock pulse of an oscillator 100 designed as a quartz oscillator and having clock frequency f_{quartz}. The accumulator then overflows periodically due to the constant incrementing. The value curve in the accumulator over time corresponds to a sawtooth function having value range 0 to $2^N - 1$ (N may be 32, for example). The values in the accumulator are interpreted as phase value

$$F = (2*\pi*Z)/2^N$$

of a cosine oscillation. By using a ROM table and/or algorithmic methods, a sample value cos(F) of the cosine oscillation is formed from this phase value. This sample value

is output via a D/A converter and filtered through a low-pass filter accordingly, yielding a time-continuous cosine analog signal of frequency

$$f = f_{quartz}*Z/2^N.$$

Direct digital synthesizers are essentially known as integrated circuits and form a DDS unit. Using this integrated circuit, high-precision frequency generators are inexpensively tunable in the range of 0 to approximately 1/3 the fundamental frequency with a high resolution by programming using a fundamental frequency.

According to the present invention, two AOM frequencies f_1 and f_2 are generated by separate DDS units 110, 120, an increment value Z_1 for DDS unit 110 and an increment value Z_2 for DDS units 120 being preselected. It is also characteristic that the fundamental frequency for both DDS units 110, 120 is formed by a common oscillator 100.

The following equations are obtained for AOM frequencies f_1 and f_2, heterodyne frequency f_{Het} and increment values Z_1 and Z_2:

$$f_1 = f_{quartz}*Z_1/2^N$$

$$f_2 = f_{quartz}*Z_2/2^N$$

$$f_{Het} = |f_1 - f_2| = f_{quartz}*(|Z_1 - Z_2|)/2^N.$$

In the exemplary embodiment shown here, sample rate f_a of A/D converter 80 is obtained by direct division of frequency f_1 by an integral factor N_1. This is implemented in an integrated divider unit 130, for example.

With regard to the precision of sampling by A/D converter 80, it may be advantageous if sampling rate f_a amounts to exactly k times heterodyne frequency f_{Het}, where k is an integer.

This yields the following equation:

$$f_a = k*f_{Het} = f_1/N_1.$$

The following equation is thus obtained for division factor N_1:

$$N_1 = \{f_1/(k*f_{Het})\} \text{ rounded.}$$

Since Z_1 must be an integral multiple of N_1*k, this yields the following equation for Z_1:

$$Z_1 = k*N_1*\{(2^N*f_1)/(k*N_1*f_{quartz})\} \text{ rounded.}$$

For Z_2 it then holds that:

$$Z_2 = Z_1*\{1 + 1/(k*N_1)\}.$$

In one exemplary embodiment the following values are selected:

$f_{quartz} = 120$ MHz,

f1 = approx. 34.9 MHz and f_2 = approx. 35.1 MHz and thus f_{Het} = approx. 0.2 MHz,

$k = 4$.

These are obtained with $N = 32$ and $N_1 = 44$ by selecting

$Z_1 = 1249119696$ and $Z_2 = 1256216967$,

which thus yields:

$f_1 = 34.9000011$ MHz and $f_2 = 35.0982966$ MHz,

$f_{Het} = 0.1982955$ MHz and $f_a = 0.7931818$ MHz.

Figure 3 shows another embodiment of an oscillator system for a heterodyne interferometer. In contrast to the embodiment illustrated in Figure 2, sampling frequency f_a is generated by a divider unit 140 from frequency f_2. The following equations are obtained analogously to the exemplary embodiment described above:

$f_a = k*f_{Het} = f_2/N_2$

$N_2 = \{f_2/(k*f_{Het})\}$ rounded

$Z_2 = k*N_2*\{(2^N*f_2)/(k*N_2*f_{quartz})\}$ rounded

$Z_1 = Z_2*\{1 - 1/(k*N_2)\}$

The following values are selected in this exemplary embodiment:

$f_{quartz} = 120$ MHz,

$f_1 =$ approx. 34.9 MHz and $f_2 =$ approx. 35.1 MHz and thus $f_{Het} =$ approx. 0.2 MHz,

$k = 4$.

These are obtained with $N = 32$ and $N_2 = 44$ by selecting

$Z_1 = 1249140025$ and $Z_2 = 1256277968$,

which thus yields:

$f_1 = 34.9005691$ MHz and $f_2 = 35.1000009$ MHz,

$f_{Het} = 0.1994318$ MHz and $f_a = 0.7977273$ MHz.

Thus, on the whole, corresponding frequencies for heterodyne interferometers are achievable inexpensively using the DDS units described above because high precision frequencies may be generated, yielding a particular frequency stability which is advantageous for certain measurement jobs.